

**Sewage Discharge Pump
Topic N99-121
Phase-I Final Report**

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**Prepared for:
Naval Sea Systems Command
Arlington, VA 22242-5160**

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13. ABSTRACT (Maximum 200 words) Report developed under SBIR contract for topic N99-121. Barber-Nichols Inc. has completed a preliminary design of an innovative sewage pump. Initial analysis, material selection, and pump layout drawings have been finished along with the Phase-I final report. The pump design features a hermetic electric motor / pump housing that eliminates the troublesome pump seal and utilizes a unique mechanism chopping solids at the pump inlet. The pump motor and bearing system is cooled, lubricated, and purged with a small flow of fresh water thus eliminating the typical oil system. The report outlines the research and testing conducted to select the most effective chopping technology incorporated into the pump design. The design solves the two major failures in the current Naval sewage CHT systems - pump seal leakage and comminutor plugging. The pump is applicable for many marine wastewater-pumping applications (both civilian and military). Other industries that could utilize this technology include residential wastewater lift stations, food processing waste handling operations, the pulp and paper industry or any pumping application that might require the transfer of waste solids.				
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SEWAGE DISCHARGE PUMP

TOPIC N99-121 PHASE-I FINAL REPORT

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REPORT SUMMARY:

Barber-Nichols Inc (BNI) has finished a preliminary design of an innovative sewage pump for use in Naval shipboard Collection Holding and Transfer (CHT) systems. The attributes that set this pump apart from others in the solids pumping market is an integral chopping mechanism incorporated with a hermetic motor design yielding a high-reliability / low-maintenance pumping system. This pump will solve the two largest problems with the current CHT systems – pump seal leakage, and comminutor plugging.

A hermetic (canned) motor is used in the BNI pump, which eliminates the troublesome pump seal and yields a totally leak-proof design. A small flow of fresh water is purged through the motor and combines with the pumped effluent providing several desirable benefits. The purge water keeps the motor / bearing cavity, free of contamination, cools the motor and minimizing pump room heating. Further, water purge allows for a robust fluid film / hydrodynamic bearing system – a bearing system containing no oil or grease and requiring little maintenance.

Additionally, the new pump incorporates a rugged chopping mechanism at the pump inlet. Chopping the sewage at the pump inlet eliminates the high-maintenance comminutors in the current Navy CHT systems – yielding a simplified and more compact system.

Significant Phase-I resources were directed at researching and testing the most effective chopping-pump technologies commercially available. Two separate test-loops were constructed and used in this research. The final (patented) chopping impeller technology selected for use is that of the Vaughan Company (with BNI refinements).

The BNI pump is designed for easy retrofit into existing CHT systems. The pumps will fit within the space envelope occupied by the pumps they are replacing with only minor spool piece changes. Pump electric power requirements are comparable to the power consumed by the pump / comminutor combination it is replacing. The new pump is constructed of highly corrosion resistant materials and is design to last the life of a Navy ship. The pump, with very little preventative maintenance, will deliver long and trouble-free performance.

With this report, BNI concludes the Phase-I effort. Detailed layout drawings of the hermetic chopping pump are also enclosed.

BNI will pursue Phase-II funding. BNI has laid the framework for a commercial partnership with the Vaughan Company to leverage the technical strengths of both companies to achieve the finest pump possible.

The BNI pump will solve the Navy's CHT system problems. The pump is also applicable for use in sewage transfer systems on U.S. Coast Guard ships as well as civilian cruise ships. Other Industries that could utilize this technology include residential wastewater lift stations, food processing waste handling operations, the pulp and paper industry or any pumping application that might require the transfer of waste solids.

1. INTRODUCTION

This report summarizes Phase-I SBIR work done by Barber-Nichols Incorporated (BNI) under contract N00024-99-C-4087. The report presents a unique and innovative design to provide a high reliability sewage pump. This new pump design addresses and solves the two most common maintenance issues with the current Navy sewage pumps – leaking seals and comminutor malfunctions (causing blockage).

Most Navy ships utilize a type III-B Marine Sanitation Device defined as a Collection, Holding and Transfer (CHT) system. This system collects both sewage and graywater and empties them into a holding tank. Sewage pumps are used to empty these holding tanks. Because of the toxic nature of sewage, pump leaks present a serious health risk and must be prevented. Current Navy sewage pumps utilize double mechanical seals, but leaks still occur due to seal failures. These seals often fail due to running dry, insufficient oil in the seal oil reservoir and/or a number of other reasons. The mechanical seals are also difficult to repair or replace correctly. Though improvements have been made to reduce system events that cause seal failures as well as monitor when they occur, the root cause of the problem has not been addressed. That is, mechanical seals are inherently vulnerable and require a level of maintenance that is difficult to achieve in marine sewage systems. A fundamentally different pump design is needed to deliver high reliability and trouble free operation. The Barber-Nichols' pump is such a design.

Navy ships with sewage holding tanks greater than 2,000 gallons typically have a comminutor installed upstream of the tank. A comminutor is a motor driven grinder used to pulverize solids in a fluid stream and thereby prevent downstream sewage pump plugging. Yet, the comminutors used still allow plugging to occur. A line is normally installed to bypass the comminutor when failures occur. When the comminutor bypass is used however, solids pass into the tank and eventually to the transfer pump, which was never designed to handle large solids. So a failure in the comminutor, often results in a failure in the sewage transfer pump as well. The Navy's desire is for a simpler and more reliable CHT system. The BNI design achieves this objective by incorporating the comminutor function into the sewage pump. This new pump design utilizes an industry tested and proven chopping impeller technology. BN is confident this design (with the optimizations to be accomplished in Phase-II) will be rugged and more reliable than the current CHT system comminutor/pump combination.

To summarize, the BNI pump design presented and discussed in this report addresses and corrects the two most troublesome aspects of the present shipboard CHT systems – pump seal leaks, and comminutor plugging. The innovative design incorporates the following noteworthy features:

- ◆ A hermetic sealless approach that eliminates the troublesome mechanical seal found in the current Navy pumps.
- ◆ A rugged chopping impeller that macerates solids entering the pump. This pump requires no upstream comminutor as do the current Navy pumps.
- ◆ Water lubricated hydrodynamic bearings for long-life and the elimination of the oil and grease needed by rolling-element bearings found in the current Navy pumps.

- ◆ To achieve the hermetic design, the electric motor will be canned to isolate it from the flushing water used to keep the motor cavity free of contaminants.

The BNI pump is a fully integrated design combining the pump wet-end and the electric drive motor into a single hermetic unit. This approach results in synergies that improve pump performance and reliability over more conventional (dry motor / mechanical seal / pump wet-end) designs. All of the key design features of the BNI pump will be discussed in detail in a later section of this report.

2. PHASE-I TECHNICAL OBJECTIVES

The goal of Phase-I was to develop the best preliminary design possible of a reliable and capable sewage pump for retrofit into Naval CHT systems. The pump design must be low-maintenance, leak-free, and eliminate the need for a comminutor in the CHT system.

To accomplish this goal the following specific objectives were completed.

1. Researched and defined the requirements for a reliable, maintainable CHT pump that will chop solids to a manageable size at the inlet.
2. Evaluated BNI chopping impeller concepts as well as commercially available chopping/grinding pump technologies.
3. Selected and tested the most promising chopping/grinding pump technologies.
4. Performed preliminary pump design analyses and created detailed conceptual layout drawings of the entire hermetic pump/motor unit.
5. Conducted preliminary research into materials for all pump components that resist corrosive attack of sewage and meet all additional performance requirements.

3. PHASE-I WORK SUMMARY

BNI has completed all of the above mentioned Phase-I objectives. To accomplish this, the work schedule outlined below was followed. Key tasks completed to reach project objective are discussed and the BNI design philosophy is indicated.

3.1 Problem definition

The first step to meeting all the Navy's performance requirements, demands a clear understanding of the total CHT system and the role of the transfer pump in the system. To gain this knowledge and understanding, Jim Dillard (New Products Manager at BNI) made a trip to the Naval Surface Warfare Center in Philadelphia on June 29, 1999. There he met with George Tabak of Naval Sea Systems Command and Michael Chapkovich, CDNSWC Code 631. Topics discussed were the modes of failure of the current shipboard sewage pumps and comminutors. The CHT system on an inactive naval ship was inspected. Photographs were taken and additional drawings and documents were given to BNI for further study. This fact-gathering trip provided BNI with a clear

understanding of CHT system problems and the system environment that the new BNI pump design must function within.

3.2 Literature search

A literature search of all relevant comminutor and chopping/grinding pump designs was completed. This research identified two general categories of pumps that can handle solids at their inlet – grinding pumps, and chopping pumps.

Grinding pumps:

These pumps comprise the largest category and are predominately used in residential applications to comminute household sewage and pump it through small diameter (1-to-2 inch) piping. Grinder-pumps are designed to cut sewage and stringy material into tiny particles, eliminating roping, and producing a fine slurry that can pass through small diameter pipes. However they will clog if a large and tough solid is encountered. The problem results from the numerous restrictive openings at the pump impeller inlet. These small opening are necessary to process the sewage to a fine slurry, however they are easily plugged by a large object bridging the entire pump inlet. Once the pump inlet is plugged, no sewage will flow through the unit and the grinding mechanism is rendered ineffective. In residential sewage systems where introduction of atypical and troublesome foreign objects into the sewage stream is unlikely, grinder pumps will perform adequately. However in the more hostile and challenging environment aboard Navy ships where shop rags and T-shirts are common sewage components, grinder pumps will not work. An alternative and more robust pump design is required.

Chopper pumps:

A more rugged family of comminuting pumps is referred to as chopping or cutter pumps. Within this area the most promising designs were found. Chopper pumps have an inlet that is significantly more open and free-flowing than the inlet of grinder pumps. Chopper pumps do not attempt to reduce the sewage solids to the small particle size produced in a grinder pump. Instead, solids are comminuted only to the size where they will reliably pass through the pump and all remaining system plumbing. The open nature of chopping-pump inlets makes these pumps less susceptible to plugging due to inlet bridging (as can occur in grinder pumps). BNI favors a chopping pump design for the Navy CHT application due to the minimum 4-inch sewage plumbing.

Barber-Nichols researched several manufacturers of chopping pumps and selected two for additional evaluation. The first pump purchased for testing was a cutter pump manufactured by Tsurumi. The second pump purchased for evaluation was a very rugged 10-hp chopper pump manufactured by the Vaughan Company.

3.3 The Eddy pump

The CHT systems addressed in this SBIR initiative does not include aircraft carriers. Aircraft carriers are an exception and their CHT systems are much larger than the systems used on the remainder of the naval fleet. The high flow rates achieved and the large pipe sizes (over 4-inch diameter) used in aircraft carrier CHT systems make them significantly less prone to plugging. BNI investigated the pumps used in the aircraft carrier systems to

see if they might also perform well in a smaller CHT system. The Eddy Pump Corporation manufactured the pumps used.

After gathering literature and talking with the Eddy Pump inventor and company CEO, Dr Harry Weinrib, it was learned that an Eddy pump does not chop or comminute the solids in the fluid stream. This pump performs satisfactorily in an aircraft carrier CHT application because the system requires a large pump with flow passage areas of sufficient size that the risk of plugging is reduced to the point that size reduction of the solids in the sewage is not required.

Because the BNI pump is to be used in CHT systems with 4-inch piping, the Eddy pump design is not consider an option. If the comminutors are to be eliminated in these smaller CHT systems, a chopping pump design must be used.

3.4 BNI pump review

Barber-Nichols presented a chopping pump design in our original Phase-I proposal document. This design was based on a previously manufactured BNI bilge pump that has operated successfully in a marine environment. After conducting the market research outlined above, the BNI design was critically compared to the most promising chopping pump technologies. BNI held meetings with both engineering and manufacturing departments to discuss the merits and perceived weaknesses of the various chopping technologies. These meetings led to the decision that the best approach to achieving success in this very demanding Navy application lie in utilizing a thoroughly tested and mature chopping pump design. This decision meant that BNI would seek to partner with a company possessing such mature chopping pump technology.

3.5 Chopping pump testing

BNI identified chopping pump performance as a critical performance criterion deserving of significant Phase-I effort. Two chopping-pump test-loops were constructed and used. The details of the test-loop construction and pump testing are covered in Section 4.

3.6 Pump/Motor integration

BNI engineers completed all appropriate analysis required to develop a good preliminary design. This chopping pump design integrates the pump wet-end with the electric motor / bearing system delivering synergies which enhance performance and reliability. The design is sealless and hermetic, and incorporates many features that BNI has developed and routinely uses in its high-performance pumps. Standard design issues receiving attention were hydrodynamic, thermal, vibration, structural, and materials compatibility. Cost and manufacturing considerations were also used to refine the design. Further analysis and design refinements are expected in Phase-II. Key pump design features are presented and discussed in section 5. Section 6 is a further discussion of preliminary pump material selections.

3.7 Pump layout drawings

In addition to this report, the pump layout drawing package comprises the set of deliverables for this Phase-I contract. The layout drawings depict an accurate

representation of the BNI chopping pump design. A color cross-sectioned view of the pump is shown in Figure 1.

4. CHOPPING PUMP RESEARCH AND TESTING

Because of the crucial importance of the pump's chopping performance to the ultimate success of the design, considerable Phase-I resources were directed to this area. Meetings were held to review the commercially available chopping pump designs and to select those that were felt the most promising for further evaluation. Two such pumps were chosen, the Tsurumi "Cutter Pump" and the Vaughan "Chopper Pump." To complete this evaluation, two different test-loops were constructed and numerous pump performance tests conducted. A review of these activities follows.

4.1 Small test-loop

The first test-loop constructed and shown in Figure 2 was built to evaluate the macerating performance of the Tsurumi Cutter Pump. The water reservoir was a 55-gallon plastic barrel and the pump was plumbed in using 2-inch schedule-40 PVC pipe. The suction line exited on the side of the barrel near the bottom and was fitted with a 2-inch ball-valve. This valve could be shut to isolate the pump for servicing. During pump testing this valve remained fully open. The pump discharge line returned through a 2-inch gate-valve. This valve was used to back-pressure the pump so that it was operating within its performance head/flow range.

Solids to be chopped were dropped into the barrel and a stick used to push them toward the inlet of the suction pipe. After the solids had passed through the pump, they returned to the barrel through the pump discharge pipe and flowed into a strainer fitted into one half of the barrel cover. The strainer was used to collect the chopped solids for later inspection.

Through use of the small test-loop it became apparent that significant uncertainty would accompany any extrapolation of small chopping pump test results. A larger test-loop would be required to confidently predict the performance achievable by a larger chopping pump of the size needed in the Navy CHT system. The value of full-flow, full-scale, empirical data was judged crucial in finalizing a pump design that could meet or exceed the Navy's expectations.

4.2 Full-scale test-loop

This test-loop used a 300-gallon polyethylene water holding tank with 3-inch schedule 40 PVC piping and allowed full-scale flow tests. This test-loop contained 3-inch PVC ball-valves near both the pump inlet and discharge. The inlet ball valve was kept full-open during all testing. The outlet ball-valve was used to throttle the flow and position the pump within its proper head/flow range. This test-loop is shown in Figure 3.

The solids to be chopped were introduced through the vertical standpipe immediately upstream of the pump inlet. In many instances it was necessary to push the solids down

the standpipe with a broomstick. The chopped solids were collected in a strainer fit into the tank's top fill port.

In addition to evaluating chopping performance, the test-loop was also used to measure the pump's head/flow curve and efficiency. These added tests required the insertion of an orifice-plate flow meter with pressure taps into the horizontal section of the pump discharge pipe just prior to its entry into the water tank. Analog pressure gauges were also installed at the pump inlet and discharge. Test results are reported in a later section.

4.3 Tsurumi Cutter Pump Testing

The Tsurumi pump was a small (1-hp) pump and featured a strongly backward-curving single-bladed impeller. A sharpened tungsten-carbide tooth was brazed into the upper leading-edge of the impeller blade. This hard tooth cuts solids by a shearing action as the blade passed beneath scalloped cutouts along the perimeter of the impeller inlet opening. This pump design has a generous impeller inlet area and large flow passages. The pump is designed to transfer most solids without macerating them – only unusually large solids are cut.

The Tsurumi pump is a submersible design and therefore does not have an inlet pipe flange. Because the Navy CHT systems use inline pumps, modifications to the Tsurumi pump were required. The inlet bell-mouth was removed and a spool piece fabricated so that the pump could be tested as an inline design.

The Tsurumi pump was evaluated using the small test-loop (see Figure 2). Paper towels and shop rags were introduced into the suction line to evaluate the pump's non-clogging performance. Paper towels usually passed without problems, but the pump would not tolerate a shop rag. Even though limited motor power contributed to this pump failure, it did not fully explain it. A more fundamental design flaw is blamed. Upon disassembly of the clogged pump, it was discovered that the open nature of the impeller inlet had allowed the shop rag to "ball up" around the center impeller attachment nut thereby holding the rag in place. This prevented flow from moving through the pump and kept the shop rag away from the cutting features of the impeller. The cutting tooth finally grabbed the rag, but the motor torque was insufficient to shred the rag before the motor stalled. Figure 4 shows the clogged pump after partial disassembly.

In defense of the Tsurumi pump, it should be remembered that the pump is sold as a submersible pump. It may be that the design works much better in that configuration (with the corresponding wide-open inlet) than as an inline pump design. However since the Navy CHT system requires inline pumps, a modified Tsurumi pump design does not appear a good choice.

4.4 Vaughan Chopper Pump Testing

The next pump tested was a 10hp Vaughan "Chopper Pump." The Vaughan Company has considerable experience in manufacturing pumps that are designed specifically to handle debris-laden materials in a liquid slurry. Solids are chopped between the knife-edged impeller blades and the two stationary cutter bars that project radially inward. The

standard impeller and cutter bars are made of cast steel heat treated to 550 Brinell hardness. The pump also incorporates additional cutting features around the impeller attachment nut and behind the impeller. The Vaughan impeller is shown in Figure 5.

This pump was installed in the larger test-loop shown in Figure 3. The pump evaluated was a 10-hp belt-driven unit rotating at 1200rpm. The 8.9-inch chopping impeller had two blades and was rated to deliver 30-ft of head with a flow of 140-gpm when pumping water. The electric motor was wired through a variable frequency drive (VFD) so that the pump could be tested at different speeds. Motor power was sufficient to allow testing at speeds as high as 1500rpm.

4.4.1 Chopping Performance

The Vaughan pump performed very well handling the wide range of solids tested. The stock Vaughan pump (tested at 1500 rpm) successfully chopped and pumped the following:

- ◆ Paper towels and cardboard scraps
- ◆ Large wads of plastic pallet wrap and plastic banding
- ◆ Shop rags and panty hose
- ◆ Wood blocks
- ◆ Rubber gaskets
- ◆ A makeshift mop head.
- ◆ Golf balls
- ◆ Aluminum beverage cans
- ◆ Plastic hair brush
- ◆ Several feet of $\frac{3}{4}$ -inch diameter rope

Figure 6 is a montage of materials chopped and Figure 7 shows the materials after passage through the pump. It is clear that considerable slicing of the materials have occurred.

The stock Vaughan impeller, though a prodigious chopper, does not develop sufficient head rise to satisfy Navy requirements. To partially address this performance shortfall as well as investigate chopping characteristics with different blade geometry, Barber-Nichols designed and manufactured the improved impeller shown in Figures 8 and 9. The new impeller was manufactured from 17-4 PH stainless steel and has four blades with less backsweep on the blades.

The BNI impeller was installed into the Vaughan pump housing and presented the same collection of materials to chop as were used to evaluate the stock Vaughan impeller's chopping performance. The BNI impeller when tested at 1500 rpm performed similar to the Vaughan impeller with some notable differences.

The BNI impeller appeared to comminute the materials to a finer consistency. This is consistent with what was expected considering the BNI impeller has twice the number of blades as the Vaughan impeller – presenting twice the number of cutting

opportunities between the rotating impeller blades and the stationary cutter bars. Though discernible to the touch and to a lesser degree by eye, the differences in chopped material fineness does not show well in photographs.

The BNI impeller creates a greater inlet obstruction than does the Vaughan impeller. The consequence of this is that some solids took longer to pass through the pump when the BNI impeller was used. This was most evident when golf balls and wood blocks are introduced to the pump. The BNI impeller, with its additional blades will not allow the solids to ingress as deeply between the stationary cutter bars as is possible with the two-bladed Vaughan impeller. This causes the BNI impeller to “nibble” away the solid in smaller “bites” than does the Vaughan impeller – extending the time required to chop and pass the solid through the pump.

4.4.2 Head / Flow Performance

As mentioned above, the downside of the two-bladed Vaughan impeller is that it does not develop sufficient head rise to meet Navy requirements (50-to-90 ft). BNI sought to show that an impeller redesign could produce higher head while retaining the favorable chopping characteristics of the Vaughan impeller. The BNI impeller did achieve this goal. The degree of performance improvement was limited however. A significant constraint placed on the BNI design was the necessity for the impeller to fit within the Vaughan pump housing (this prevented a change in blade height).

Hence, this BNI impeller is not an optimized design. Both the pump impeller and volute must be designed together to achieve high pump performance. In addition, a change in blade height is likely needed to meet the Navy’s head / flow requirements. Funds were not available to accomplish this in the Phase-I effort. The pump design presented in this report will be refined and optimized in the Phase-II effort. Further investigation into different blade numbers and angles will be completed to determine maximum cutting and pumping performance for a variety of solids.

Still, the first-cut BNI design showed improvements over the Vaughan stock impeller in pumping performance and efficiency. This improved performance is revealed in Figures 10 and 11. Figure 10 compares the head flow curves for both the stock Vaughan impeller and the BNI impeller. Both impellers were tested with the VFD set at 65Hz – yielding a pump speed of 1300 rpm. The figure shows that the BNI impeller develops an additional 5 pounds of discharge pressure (i.e. 12 ft of head). Figure 11 compares the pumping efficiency of the two impellers and shows that the BNI impeller is nearly 10 percent more efficient than the Vaughan impeller (34% vs 31%) at a flow rate of 150 gpm.

5. PUMP DESIGN DETAILS

Barber-Nichols (BNI) has developed an innovative hermetic chopping-pump design for easy retrofit into Navy shipboard sewage collection, holding and transfer systems (CHT). The rugged chopping impeller of the BNI pump will allow the removal of CHT comminutors –

simplifying the system and reducing maintenance. The near maintenance-free BNI pump has no mechanical seal and is inherently leak proof. The design will meet the Navy's stringent no-leak CHT pump requirements and eliminates the maintenance required in pumps with a mechanical seal. Figure 1 shows a cut-away view of the pump (see the included drawing package for additional views and details).

The Navy CHT systems come in a variety of sizes based on the ship class. The highest horsepower and head pumps are used on aircraft carriers. The SBIR contract awarded, instructed BNI to design a pump not for aircraft carrier applications, but for use in all other ships with type-III-B CHT systems. The BNI sewage pump is easily adaptable to cover this pump capacity range (7.5-15 hp, 100-150gpm, 50-90 feet head). The important design features of the pump are discussed in the following sections.

5.1 Hermetic Sealless Design

The BNI pump design is a once-and-for-all solution to the Navy's problems of seal failures and leaks. The BNI pump does not require a leak-free seal to achieve a leak-free pump. Conventional pumps attempt to seal and isolate the pump housing from the motor housing through use of a mechanical seal at the rotating shaft. Sealing against a rotating shaft is nearly impossible to accomplish and maintain for an extended period of operation. The necessary rubbing of surfaces in a mechanical seal, at best, gives the seal a finite life.

BNI uses a completely different approach in its pump design. BNI's pump has a close-running (but non-contacting) labyrinth. By utilizing a small water purge flow through the motor, BNI effectively moves the sealing point from the rotating shaft surface to static motor housing gaskets. Sealing at a static interface is very reliable and no wear can occur between the nonmoving sealing surfaces. The BNI pump will not leak.

Sealless, hermetic pump designs are not new to BNI. Virtually all cryogenic pumps manufactured by BNI are sealless, hermetic designs and have been operating leak-free since their installation.

5.2 Chopping Impeller

Development of an effective and trouble-free chopping impeller was identified as a key design challenge. Barber-Nichols was determined to achieve success in this critical area of pump performance. BNI has abundant experience in designing high-efficiency pumps, but has limited background in macerating pumps. BNI judged it inefficient (from both a time and cost standpoint) to embark on a research program to develop a rugged chopping impeller design when such designs already exist. Instead, BNI sought to partner with and utilize the expertise of a company with a mature chopping impeller technology. Market research directed to this goal led BNI to the Vaughan Company. BNI is confident this corporate partnership is the best approach to meeting the demanding Navy CHT pump requirements.

The BNI designed pump outlined in this report features the patented chopping impeller technology of the Vaughan Company further enhanced through BNI fluid flow analysis and design input. Barber-nichols has had discussions with Vaughan executives, and a

preliminary partnership established to pursue Phase-II options. The standard Vaughan impeller chops well but is not optimized for the Navy CHT application. BNI will determine the best impeller material to use and the blade geometry changes needed to meet Navy pump performance requirements.

5.3 Hydrodynamic Bearings

Bearing life and required bearing maintenance are key factors affecting pump reliability and operational costs. Hydrodynamic bearings are used in the BNI pump design to assure a long trouble-free life. These bearings will be located on the motor side of the pump and used for both the axial and radial support of the entire rotating assembly. A special composite bearing material of PTFE in porous bronze (Garlock DU) was selected. This bearing material's inherent lubricity allows it to absorb the shock and consequent hydrodynamic fluid film breakdown that may occur when the chopping mechanism encounters larger solids. The bearing material also displays favorable corrosion resistance. In Phase-II, bearing clearances will be optimized for the lubricating qualities of water and the speed variation the pump would experience in normal operation. Barber-Nichols has extensive experience with the design and development of water lubricated bearings.

An additional benefit that results in the use of hydrodynamic bearings is the elimination of all oil and grease products in the pump. Oil and grease are controlled substances aboard Naval ships and have additional costs associated with their use and proper disposal. The water used for bearing lubrication in the BNI design simply exits into the sewage stream and is disposed of automatically with the pumped effluent.

5.4 Fresh Water Flush

A small flow (0.4 gpm) of fresh water will be injected into the motor cavity to serve as a barrier fluid and to lubricate the hydrodynamic bearings during operation. This continual purge of fresh water will not allow sewage to contaminate the pump motor or bearings. The water injection pressure will be at a higher pressure than the highest possible suction pressure of the pump (lift available when the tank is at maximum level). The water will also cool the motor and prevent overheating. The water flow into the unit can be reduced during those times when the pump is not running, but should not be completely turned off.

5.5 Labyrinth Buffer Element

The hermetic design utilizes a non-contacting close clearance labyrinth to provide a barrier between the pump and motor. This close clearance element (typical 0.003-inch radial clearance) throttles a small amount of leakage from the motor/bearing side to the pumping element side of the unit thus keeping sewage out of the motor. The toothed labyrinth will be machined from bronze and fit closely around the rotating motor shaft. The motor shaft will be flame-sprayed with an aluminum oxide coating at the labyrinth's axial location. For added protection from sewage ingress into the motor cavity, a PTFE lip seal will be placed in front of the labyrinth. The lip seal is oriented to act as a one-way valve – allowing the higher water pressure within the motor cavity to egress, but preventing (if water purge was interrupted) sewage from back-flowing into the motor.

5.6 Canned Electric Motor

The BNI pump is a close-coupled design with the impeller directly attached to the motor shaft. The pump uses a 4-pole, 60Hz, AC induction motor with a horsepower rating from 7.5-to-15 (depending on pump head requirements) and runs at 1750 rpm. A variable frequency drive (VFD) is not required. The pump motor stator and rotor will be canned to isolate the electrical components from the injected water. This ensures motor integrity and reliability for the life of the pump. The canning material chosen is Hastelloy C-22 for its favorable electrical properties and corrosion resistance. Barber-Nichols has extensive experience with canned motors and continues to investigate cost reduction methods for canning electric motors.

5.7 Motor Control

In a pump design such as this where nearly any material might enter the pump inlet, provisions for complete system upsets must be investigated. Barber-Nichols will test a motor controller to reverse direction of the pump motor for a brief period on an overload trip in Phase-II. This would allow any solid material preventing rotation of the impeller to be thrust back into the pump inlet for another approach to the cutting mechanism. This same controller could be designed to shut-down and sound an alarm if after a number of attempts, the obstruction has failed to be dislodged.

5.8 Pump Interface and Sizing

The BNI sewage pump is designed to be a near bolt-in replacement for the current troublesome CHT pumps. Several of the key pump interface dimensions match those of the current pumps. These dimensions are:

- ◆ The pump inlet flange height
- ◆ The pump discharge flange height
- ◆ The radial offset dimension of the pump discharge flange to the pump inlet flange
- ◆ Both inlet and discharge flange bolt patterns

The one key pump wet-end dimension that could not match the current CHT pumps is the axial offset of the pump discharge flange to the pump inlet flange. An additional 3-inches was required to accommodate the chopping mechanism. Shortening the length of the spool piece used to connect the pump to the CHT piping easily accommodates this change in dimension. Reference the included drawing package for additional details.

The BNI pump is actually a family of pumps covering the entire CHT system requirements (7.5-15 hp, 100-150gpm, 50-90 feet head). The design uses a single sized pump and motor housing and alters performance through impeller trimming and changes in electric motor components. This approach leverages economies-of-scale to keep pump manufacturing costs low. Also having externally identical pumps simplifies installation because all ship pump-mounting base frames can be the same.

6. PUMP MATERIALS SELECTION

The Navy CHT system subjects the transfer pumps to a very corrosive sewage/seawater environment. Sewage by nature is highly corrosive, especially when it becomes septic and anaerobic bacteria begin to generate hydrogen sulfide and sulfuric acid. Sulfuric acid obviously adds to the corrosion problems, but hydrogen sulfide and other gases, as well as pathogens in the sewage create serious health and safety concerns. It is crucial that the CHT system and all component parts be leak-free. The proper selection of materials is very important to meeting this system goal. Phase-I funding did not allow the exhaustive materials research necessary to properly address this critical issue. A significant portion of Phase-II funding will be targeted toward selecting the optimal materials to use throughout the pump. Only cursory attention was given to this subject and the materials listed on the Phase-I pump layout drawing should be considered preliminary and subject to change following Phase-II research. A brief materials selection list is presented in Table 1.

Table 1. Major pump components and preliminary material selection.

Component Description	Material
Pump Volute Housing	cast CF-3M stainless steel
Impeller	Ni-Resist
Front Cutter Bar	Ni-Resist
Labyrinth Carrier	Ni-Resist
Labyrinth	Bronze
Journal Bearings	PTFE coated porous bronze (Garlock DU)
Thrust Bearings	PTFE coated porous bronze (Garlock DU)
Motor Shaft	17-4 PH stainless steel
Motor Housing	cast CF-3M stainless steel
Stator/Rotor Cans	Hastelloy C-22
O-rings	Buna-N
Lip seal	316 SS / PTFE

Phase-II effort will be directed toward refining these material selections. It is important that the new sewage pump performs successfully, but costs must be contained. Corrosion resistant material are nearly always more costly than materials that corrode. Therefore, it will be very important to determine the most cost-effective materials to use for all key pump components.

The preliminary pump volute and motor housing material chosen is cast CF-3M stainless steel. This alloy is similar in chemical composition and corrosion resistance to 316 stainless steel. During a meeting at BNI with George Tabak, Kurt Neff, and Robert Seheps concern was expressed that stainless steel may be troublesome in a naval sewage pump. This comment was prefaced with a story of a stainless steel ladder in a CHT holding tank that had corroded away. 316 SS is a common material used in commercial seawater pumps and also in sewage pumps, but the combination of sewage and salt water is a unique aspect of the Navy sewage application. It is unclear the exact mechanism that caused the ladder to corrode, but BNI suspects a galvanic couple may have contributed. BNI will revisit this issue in Phase-II and use knowledge gained to reevaluate the pump housing material selection.

The best material choice for the impeller and cutter bars will also receive considerable attention during the Phase-II effort. The challenge to overcome is that corrosion resistant materials tend to be relatively soft. Good chopping performance requires a hard, high-strength material. Research into high strength materials with either special coatings or hardened inserts will be completed to determine which impeller material choices offer the highest corrosion and abrasion resistance. Special attention will be given to materials that resist corrosive attack from hydrogen sulfide and sulfuric acid while providing superior strength and wear characteristics. The Phase-I pump design identifies Ni-Resist as the preliminary impeller / cutter bar material choice. Ni-Resist is hardenable and corrosion resistant and a good initial material candidate.

7. COST ESTIMATE

Because of the preliminary nature and limited scope of this Phase-I effort, a firm cost estimate of the pump could not be made. In particular, the refinement of material selections in Phase-II might significantly impact manufacturing costs. At this time the best cost-estimate for the pump outlined in this report is \$20,000-to-\$30,000 in quantities of 10 or greater. Note, this pump will replace not only the current troublesome pump, but the upstream comminutor as well. The BNI pump is a cost-effective solution to the Navy's CHT system problems.

8. CONCLUSION

The pump design presented in this Phase-I report addresses and corrects the two major problems present in the current shipboard CHT systems – seal leakage and comminutor plugging. This new pump is a hermetic sealless design and features a very rugged chopping impeller / cutter-bar at its inlet that replaces and eliminates the need for a separate comminutor. The pump is leak-proof and will reliably chop all solid material present in the sewage effluent sufficiently for transfer overboard while at sea or ashore through piping when the ship is docked.

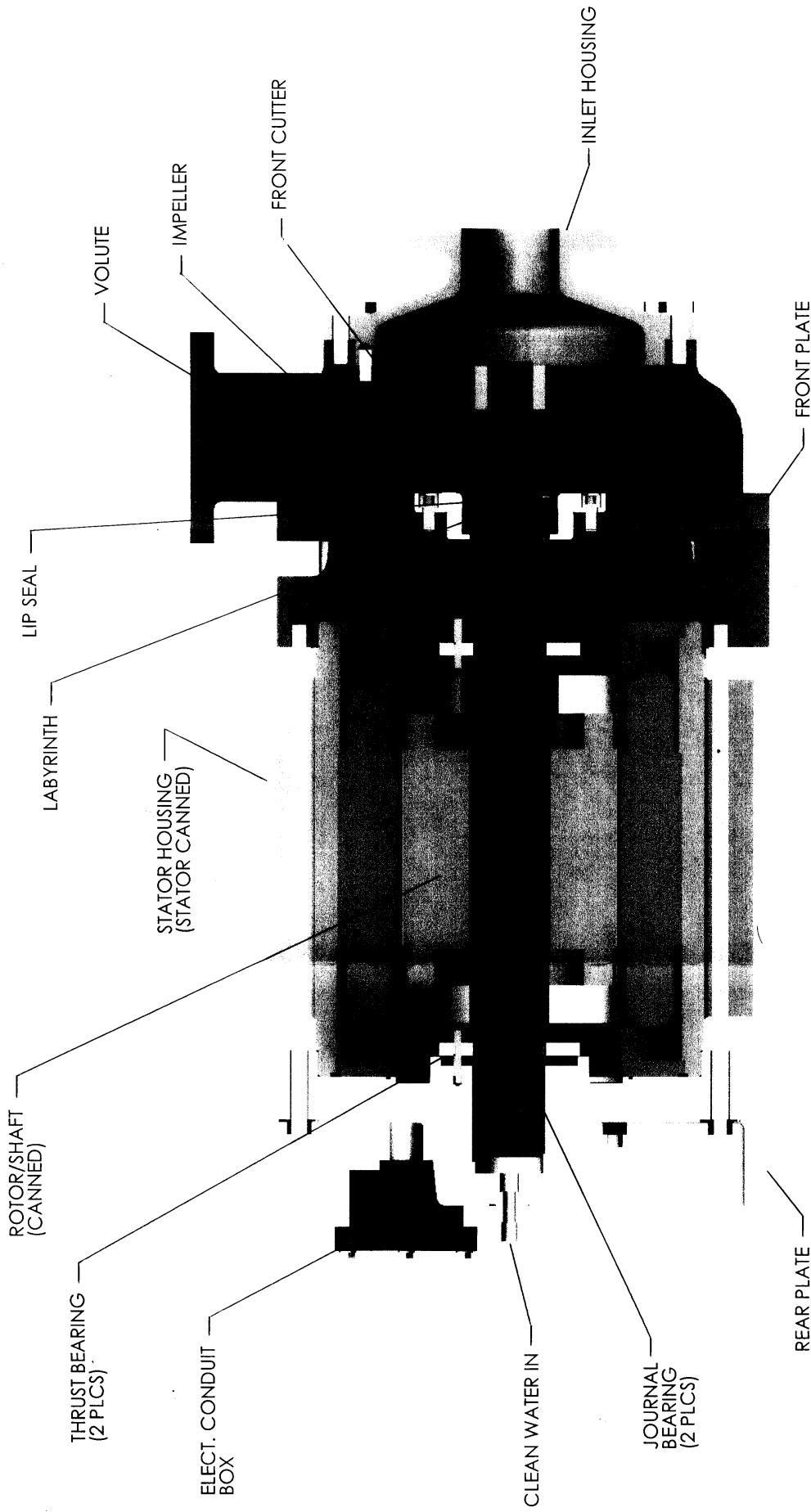
The hermetic pump utilizes a water purge to eliminate the need for a mechanical seal and results in a pump with significantly reduced maintenance requirements and increased reliability. The water purge also cools the electric motor and allows the use of fluid-film bearings. This bearing system uses no oil or grease and should achieve longer life and reduced maintenance than the rolling-element bearings used in the current pumps.

This new pump is designed for easy retrofit into existing CHT systems. The pumps will fit within the space envelope occupied by the pumps they are replacing with only minor spool piece changes. Pump electric power requirements are comparable to the power consumed by the pump / comminutor combination it is replacing. The new pump is constructed of highly corrosion resistant materials and is design to last the life of a Navy ship. The pump, with very little preventative maintenance, will deliver long and trouble-free performance.

The BNI pump is cost-effective and will succeed in solving the annoying and persistent problems in the current shipboard CHT systems.

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3. D. Demboski, J. Benson, G. Rossi, N. Leavitt, M. Mull, "Evolutions in U. S. Navy Shipboard Sewage and Graywater Programs" *Proceedings of the American Society of Naval Engineers (ASNE) Environmental Symposium "Environmental Stewardship: Ships and Shorelines," November 1997.*



BNP-20-000

FIGURE 1

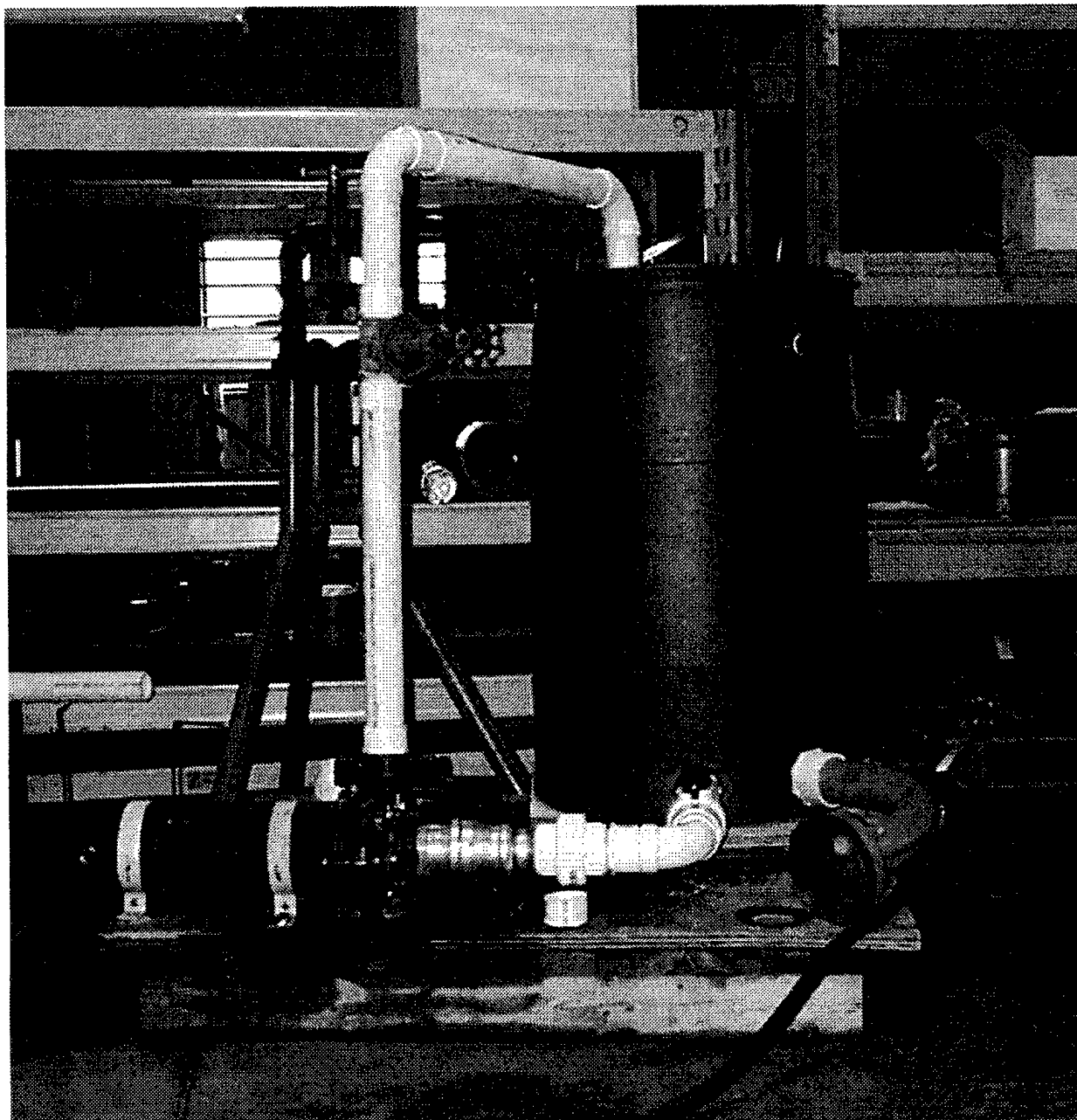


Figure 2. Small test-loop used to evaluate Tsurumi Cutter-Pump.

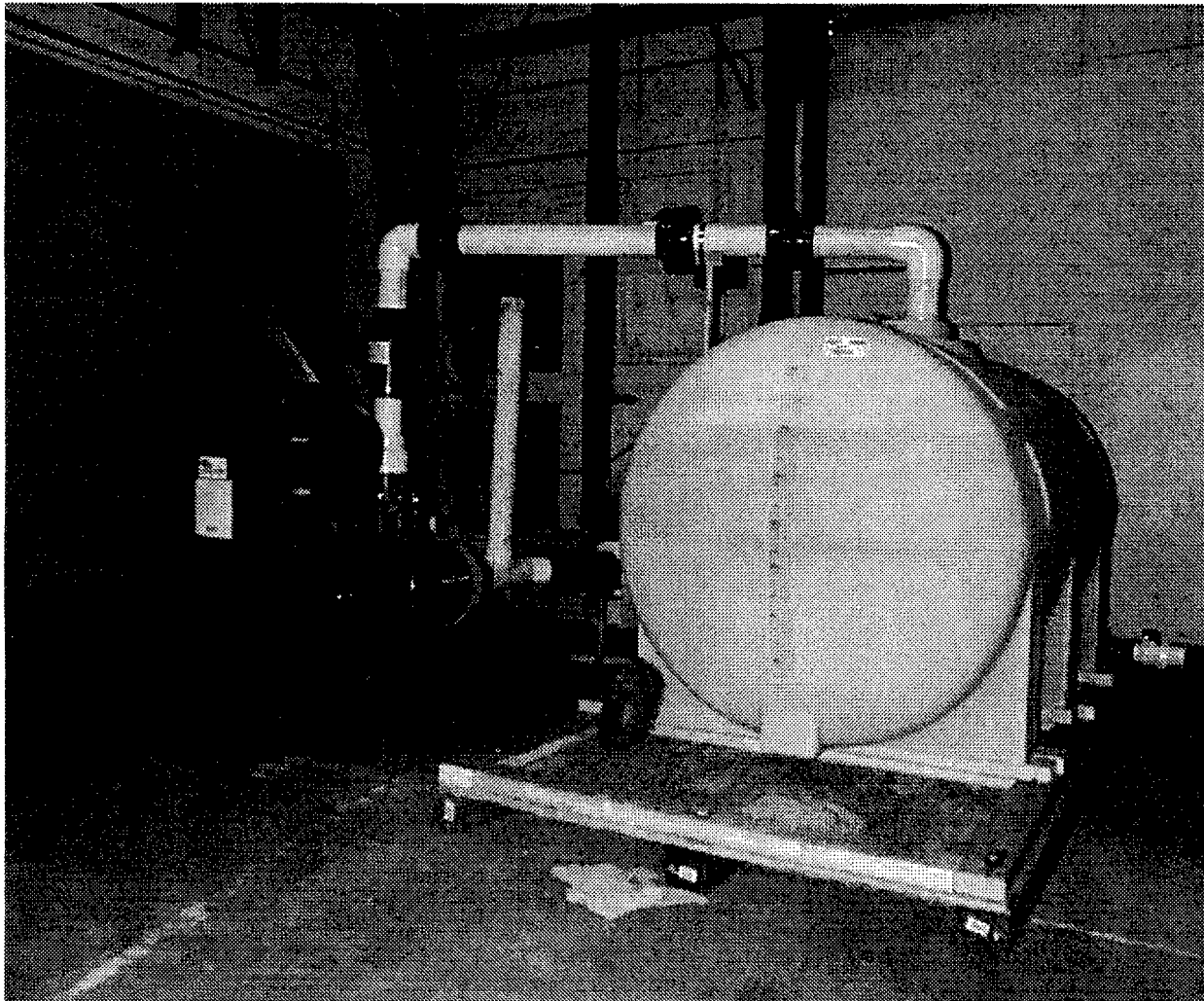


Figure 3. Full-scale 300 gallon pump test-loop.

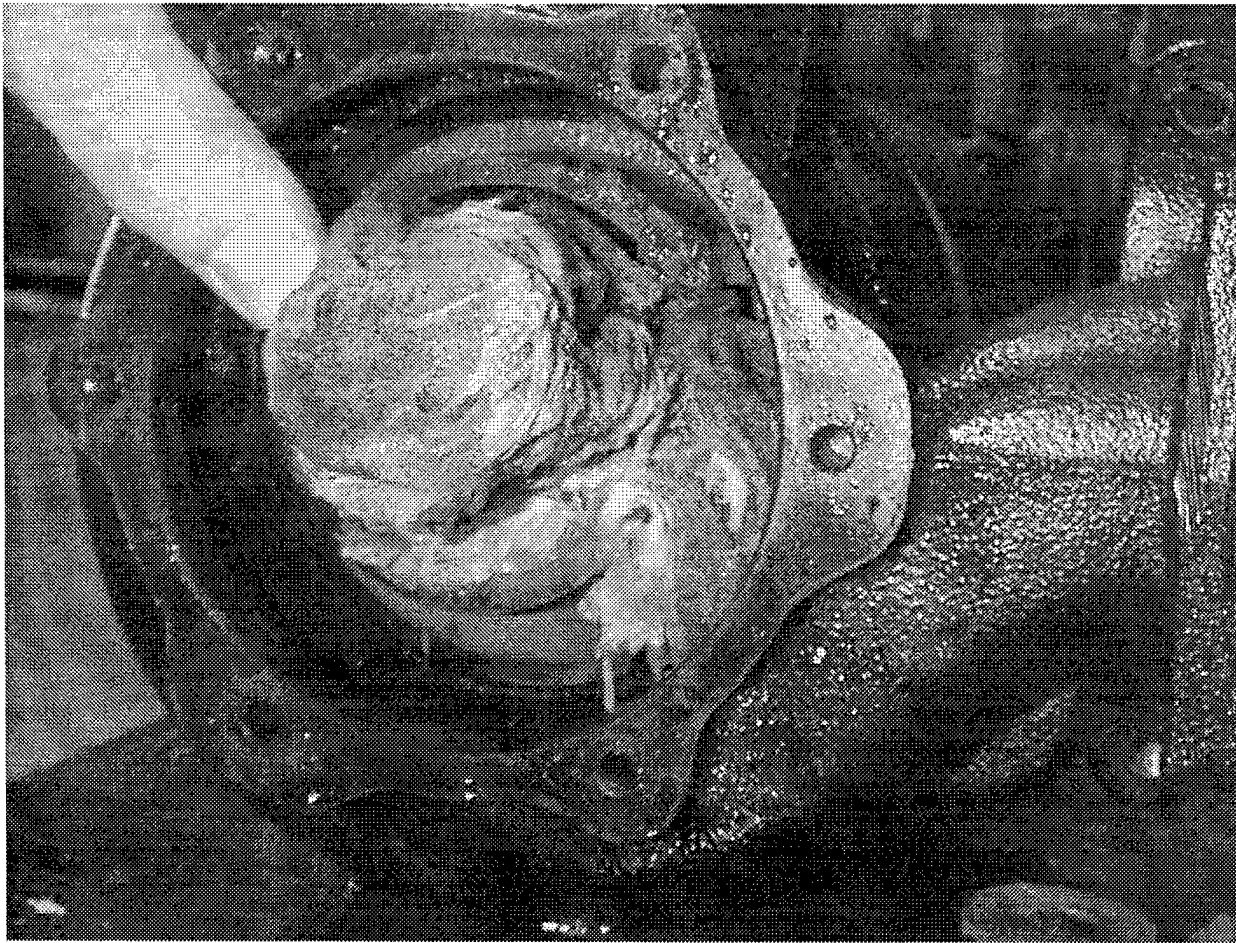


Figure 4. Partially disassembled Tsurumi pump clogged by a shop rag.

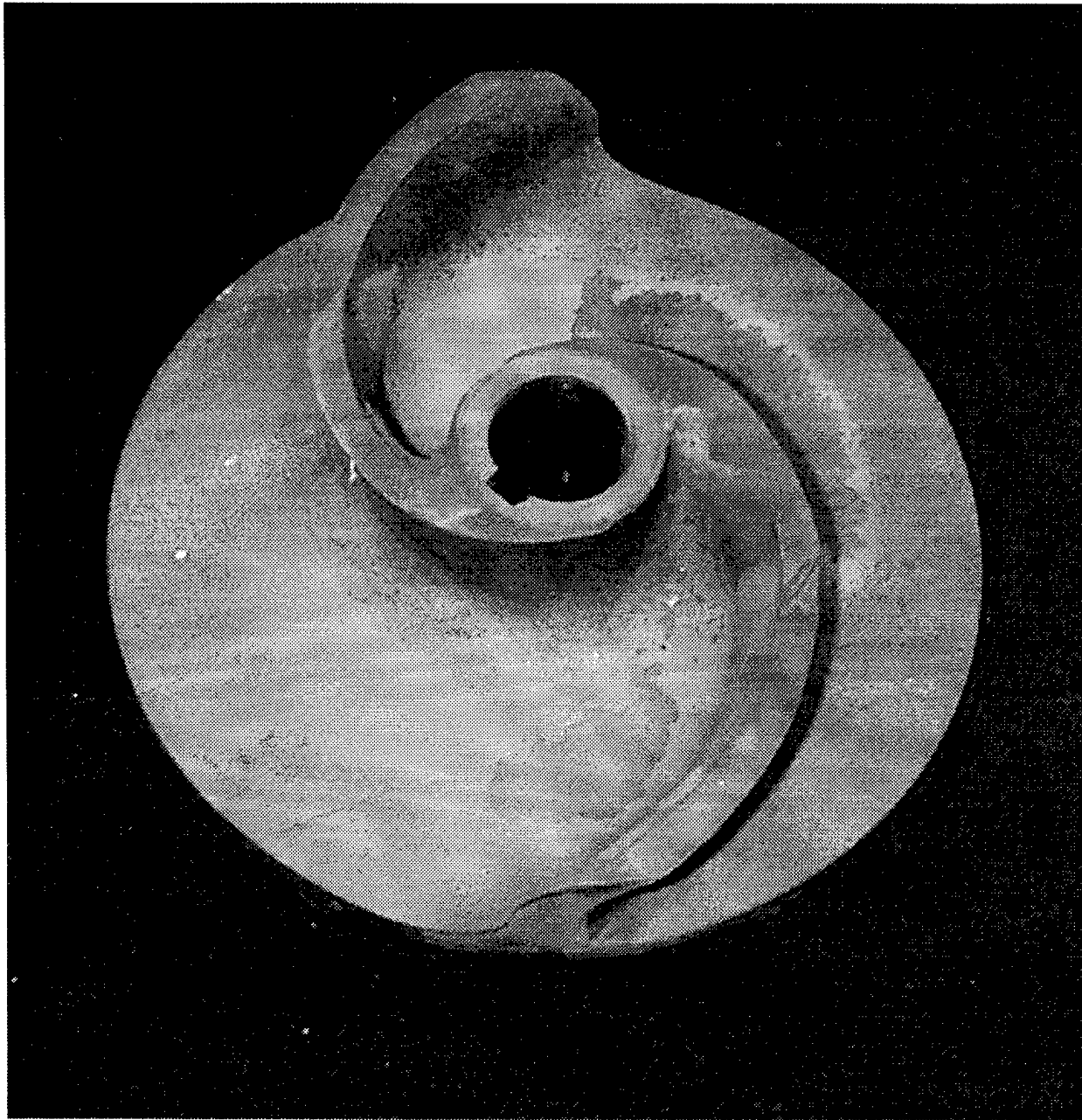


Figure 5. Vaughan Company Chopping Impeller.



Figure 6. Samples of some items (“solids”) introduced at the pump inlet.

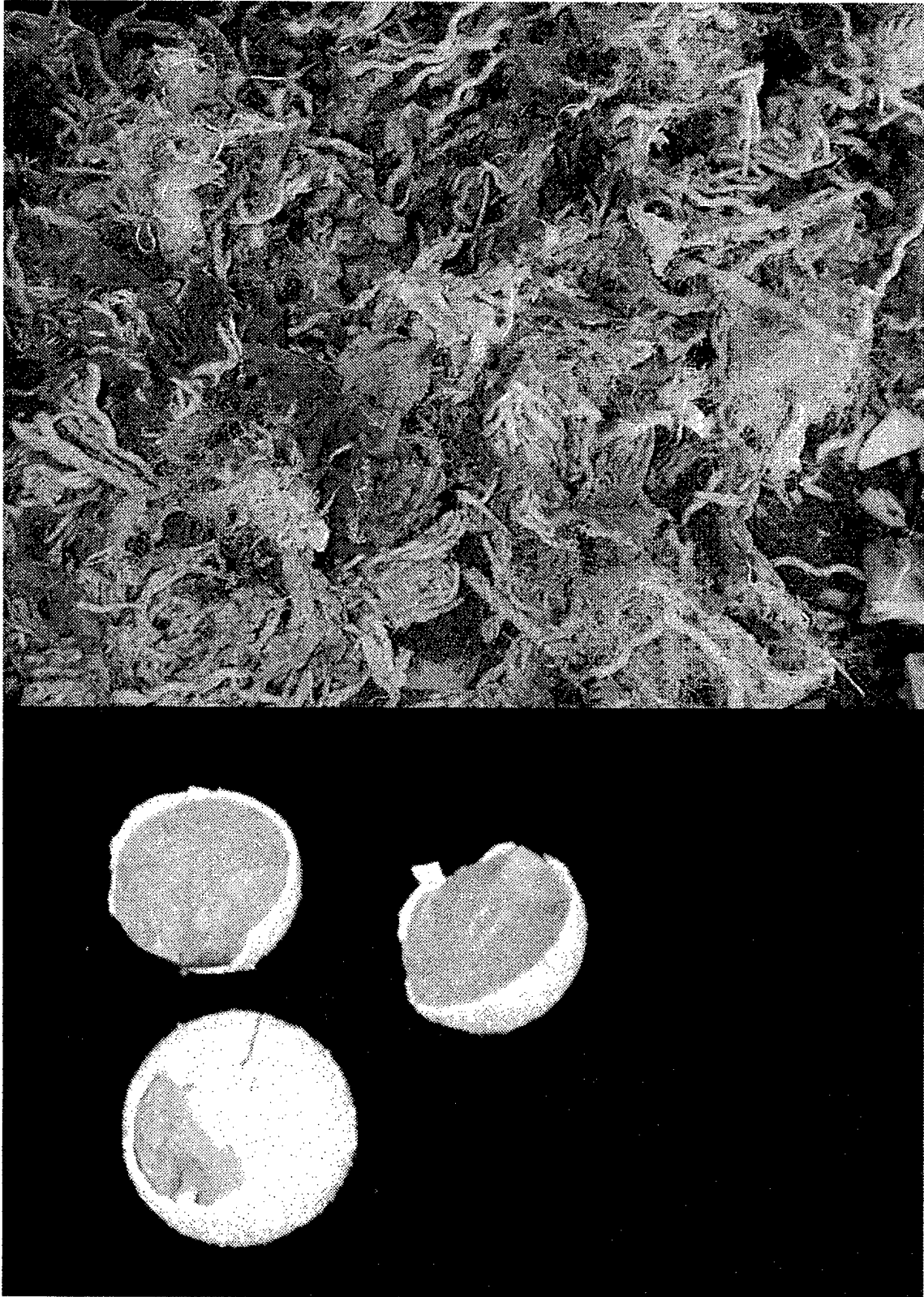


Figure 7. Chopped rags, rope, panty hose, etc. (top image).
Chopped golf balls (lower image)

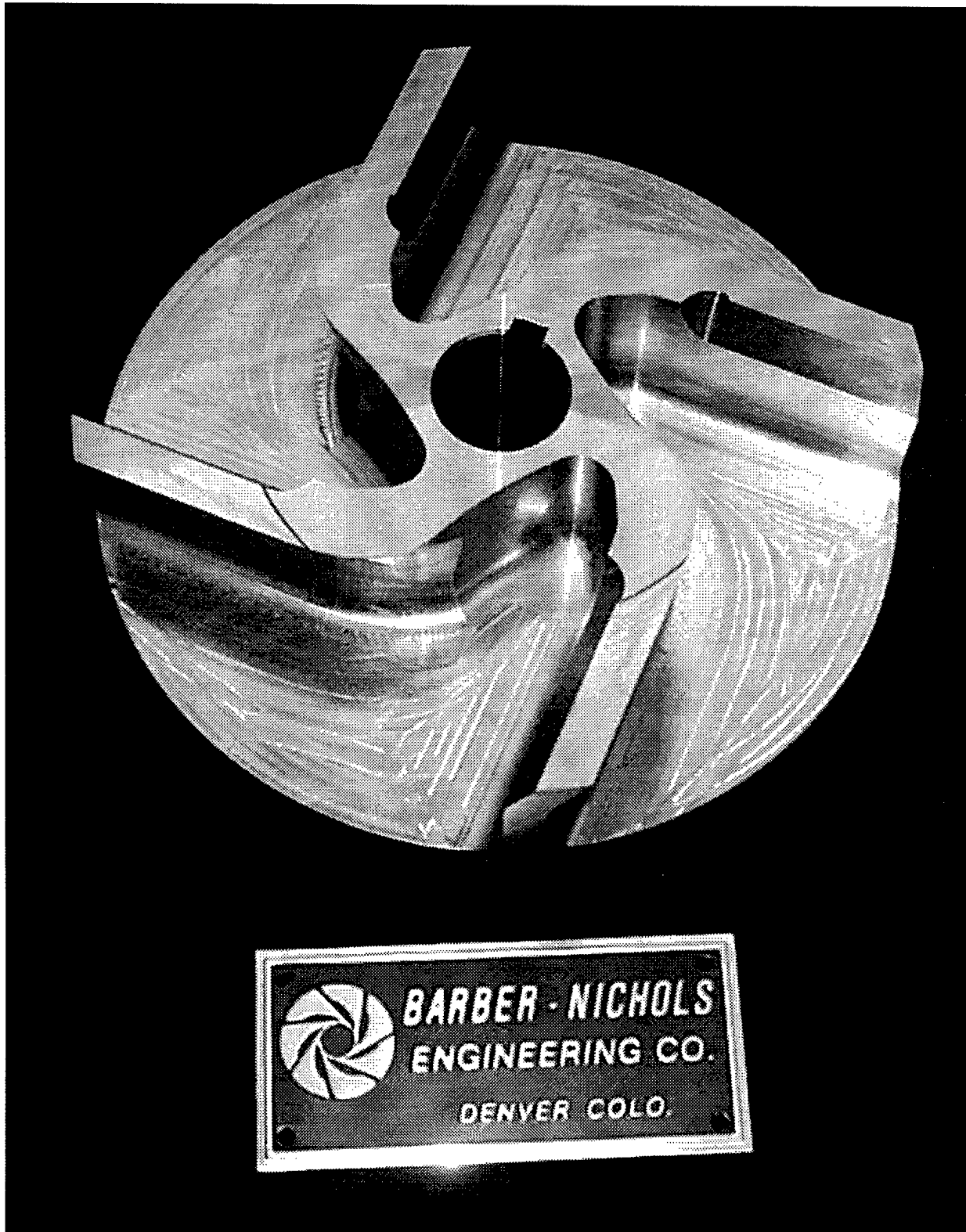


Figure 8. BNI Chopping Impeller (front view).

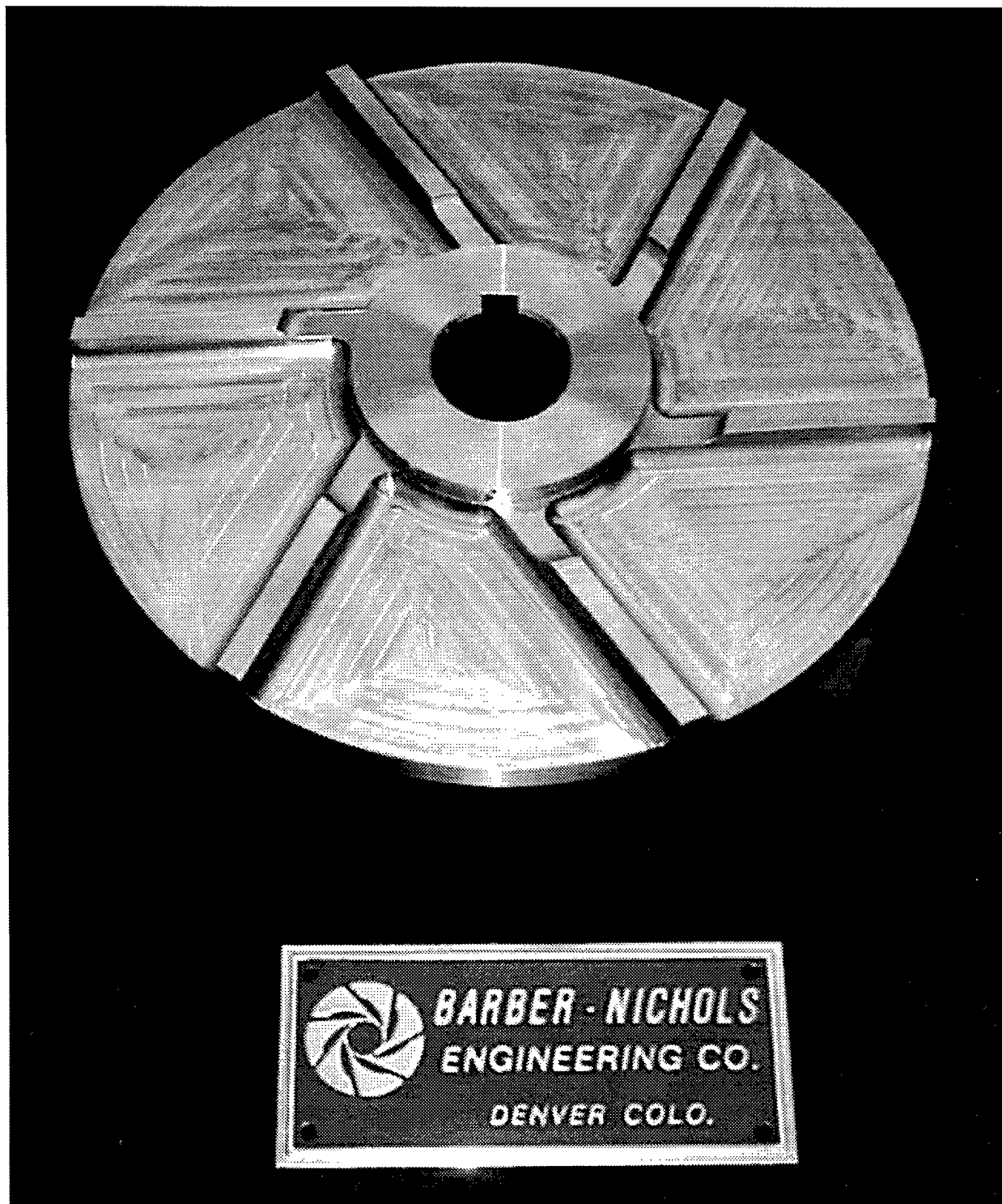


Figure 9. BNI Chopping Impeller (rear view).

Head Flow Curves, 65 Hz

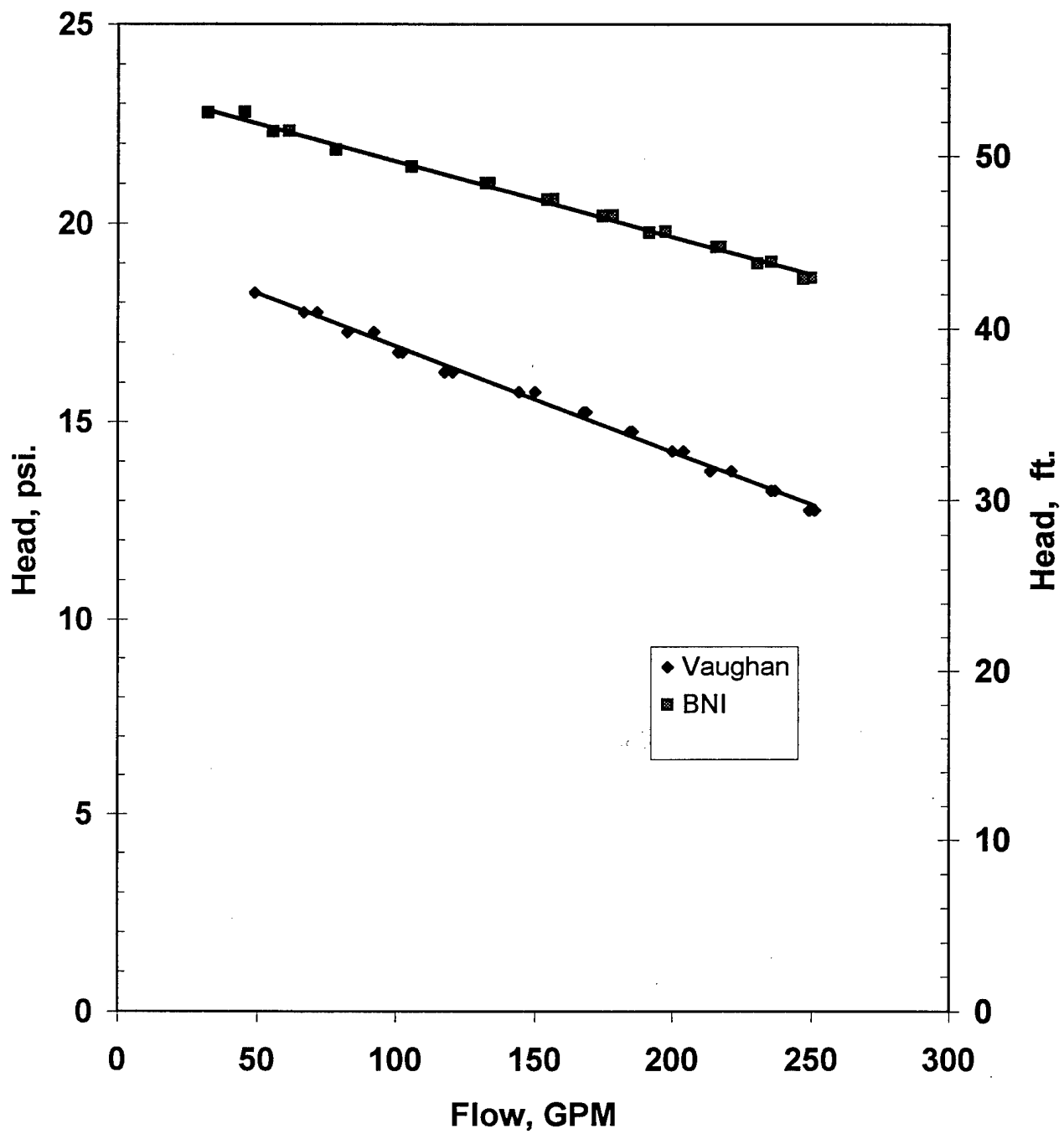


Figure 10. Head flow curve comparison of BNI and Vaughan Impellers

Pump Efficiency, 65 Hz

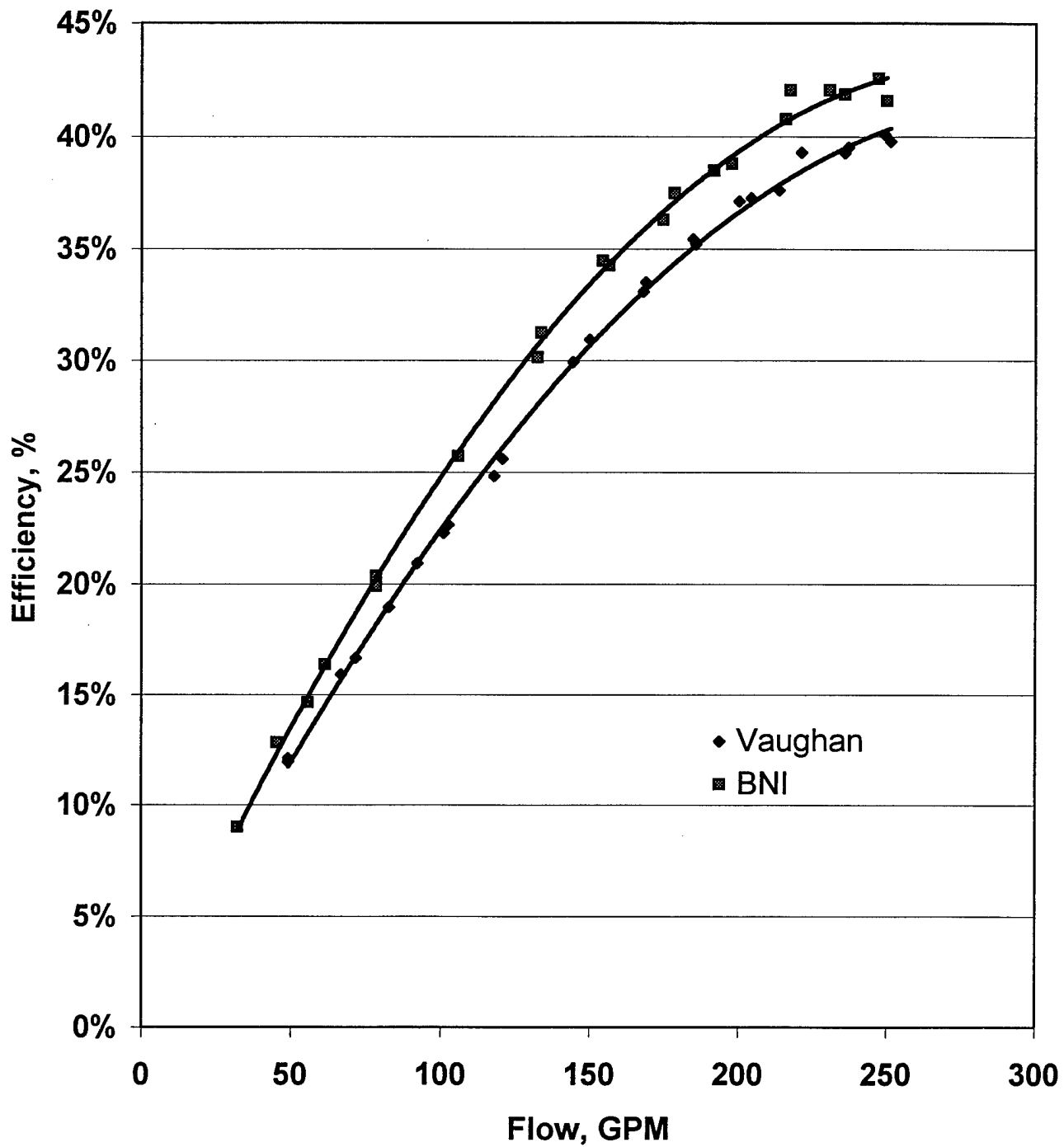


Figure 11. Pump efficiency comparison of BNI and Vaughan Impellers